Dominate time scale characteristics of the turbulence across canopy-atmosphere interface of a mixed broadleaved-Korean pine forest in Changbai Mountains

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Abstract: The measurement and observation for this study were carried out at Forest Ecosystem Opened Research Station of Changbai Mountains (128°28'E and 42°24' N, Jilin Province, P. R. China). Characteristics of Dominant time scales (DTSes) and dominant time scales contribution ratios (DCRs) across canopy-atmosphere interface and controlling factors were analyzed with multi-scale method. DTS of stream wise and lateral velocity components were larger than that of vertical velocity component. While DCR of vertical velocity component was larger than that of the stream wise and lateral velocity components. Effect of atmospheric stability on DCR and DTS was nonlinear. DTS under unstable conditions was larger than that under stable conditions; DTS and DCR were determined upon the original scales characteristics of upwind flow under strong stability. Canopy structure would influence DTS and DCR across canopy-atmosphere interface remarkably.

Keywords: Canopy-atmosphere interface; Multi-scale; Atmospheric stability; Dominate time scale;
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Introduction

Canopy-atmosphere interface, as important as the soil-atmosphere interface, is the core place for coupling of forest and environment, where energy flow and matter exchange are most frequent, bio-regulation is most active, and environmental stresses is richest (Han *et al.* 1998). The transportation of matter or energy across the interfaces is the result of multiple ecological processes at variant space-time scales. Time scale is one of the space-time scales that can describe interface processes. Different processes have influence in varied degree on energy flow and matter exchange of interface, which could be detected from multi-scale characteristics of the time scales.

The objective of this paper was to analysis the multi-scale characteristics of turbulence across canopy – atmosphere interface with multi-scales method.

Description of the experiment

Site location and Canopy

The measurement and observation for this study were carried out in No. 1 Plot at Forest Ecosystem Opened Research Station of Changbai Mountains (128°28'E and 42°24' N, Jilin Province, P. R. China), Chinese Academy of Sciences, in August 2001. The primeval forest is composed of conifer and deciduous-mixed forest. Around the observation site it is a mixed broadleaved/Korean pine forest, typical vegetation in this area, with an average tree height of 26 m. Dead trees, branches and leaves, living bushes, and ferns cover the ground of the forest.

A 62.8-m-tall meteorological tower is located at the site with an altitude of 738 m above sea level. Fig 1. Shows the vertical distribution of foliage area index (FAI) (by LI2000, Li-Cor Inc., USA). The fetch is about 60km in the prevailing wind direction.

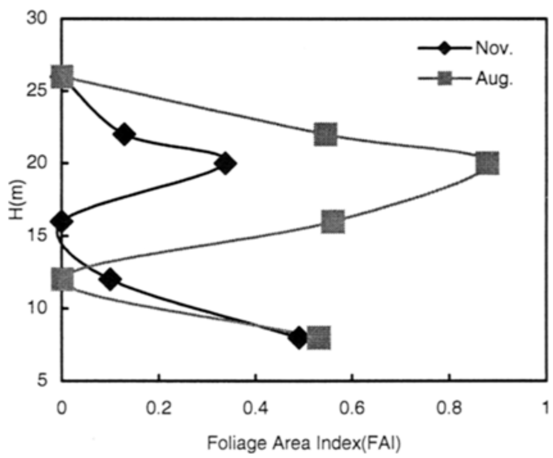

Fig. 1 Vertical distribution of FAI

Instruments and measurement techniques

One set of forest multi-parameters auto observation system, including five sonic anemometers/thermometers

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(IAP-SA485, Institute of atmospheric Physics, Chinese Academy of Sciences) and 12 CO_2 and H_2O analyzing channels were installed around forest canopy. Five sonic anemometers/thermometers were mounted separately at heights of 16 m (0.62H), 22 m (0.85H), 26 m (1.00H), 32m (1.23H), 40 m (1.54H) on the meteorological tower, and sensor heads were placed about 3 m upwind from the tower. Synchronous signals from five sonic anemometer/ thermometers were sampled at 16Hz by a desktop computer, and data were stored on hard disk for sequent analysis. The system ran continuously day and night.

Methods and data processing

Multi-scale method (MSM)

MSM is one of new methods analyzing statistical characteristics of turbulence (Xu *et al.* 1986, 1989; Xu *et al.*, 2000). The definition of autocorrelation function is

$$R(\tau) = \frac{\overline{u'(t)u'(t+\tau)}}{\overline{u'^2}}$$

Using the ESFT scheme (Wiscombe and Evans.1977), the autocorrelation function could be fitted with a combination of a group of decaying exponential functions,

$$R(\tau) = \sum_{i=1}^{n} a_i e^{-\tau/T_i}$$

where a_i, T_i meet terms: (1) $a_i > 0, T_i > 0$, (2) $\sum a_i = 1$

According Xu Dahai(1989), a_i is the weighing coefficient figuring the influence degree by the *i*th process; T_i is the time scales of the ith process.

In this paper, we would emphasize the process with largest weighting coefficient (called Dominant Process), and corresponding time scale (DTS) and contribution ratio (DCR).

Data processing

Data obtained in the middle ten days of August and November of 1999 was analyzed. Length of data segments was 30 min, 62 segments were analyzed. Horizontal coordinate rotation was made to interpret properly the measurements of the eddy correlation unit. The new coordinate system was defined such that *u* was the stream wise component of the velocity vector, *v* the lateral component of the vector, and *w* the component of the vector normal to the ground surface. Autocorrelation was calculated with IMSL Scientific computation package (Visual Numerics, Inc.) and the ESFT scheme was applied to obtain the DTSes and DCRs.

Present knowledge on atmospheric stability above and within canopy was based on the study of Hosker et al. (1974). A single scale of h/L was applied to scale the atmospheric stability condition (Leclerc and Shaw 1988; Shaw *et al.* 1988; Leclerc *et al.* 1990; Leclerc *et al.* 1991). In this paper, we also selected the single stability parameter ζ =h/L as the whole canopy condition indicator. ζ was calculated according Roland B. Stull(1988):

$$\begin{cases} u_* = \left[\left|\overline{u'w'}\right|^2 + \left|\overline{v'w'}\right|^2\right]^{1/4} \\ L \approx -\dfrac{\overline{T_v} u_*^3}{kg\overline{w'T_v'}}, \zeta = h_c / L_c \end{cases}$$

Where u_* is the friction velocity, *L* is the Monin-Obukov length; T_v is potential temperature; *k* is von Karman constant (assumed=0.4); *g* is acceleration velocity due to gravity; h_c is the average height of canopy; L_c is the Monin-Obukov length at average canopy height.

Results

Besides the original property of flow, buoyancy and mechanism shear would put effect on the turbulence scales. Local atmospheric stability parameter ζ could scale both these factors. Canopy structure could influence the scales indirectly through buoyancy and mechanism shear. We selected 3 key heights, 32 m, 22 m and 16 m, to analysis in detail.

Influence of atmospheric stability

Fig. 2 shows the influence of atmospheric stability on DTS during growth period.

For the DTS of *u* component, patterns at 32 m and 22 m were similar: they were largest under unstable condition, and reduced to a constant along with the enhancement of stability and instability. While, at the height of 16 m, the maximum value of DTS occurred under stable condition. This may be the appearance of reverse sign of ζ of 16 m and 32 m.

For the DTS of *v* component, patterns at 32 m and 22 m were similar to that of *u* component. DTSes under stable and unstable conditions were larger than that under strong stability condition.

Patterns for *w* component were very complicated. DTSes of 16 m were constant under very stable and very unstable conditions and less under weak stability. Pattern of *w* was similar to that of Stream wise and lateral velocity component at the height of 32 m; DTSes of 22 m were constant under strong stability and descended linearly from unstable to stable condition.

According Fig. 3, patterns at different heights were similar during growth-stopped period. For *u* and *v* components, there was maximum value between −1.0 and −0.5. DTSes

of *w* component descended linearly from unstable to stable condition.

Influence of canopy structure

Canopy structure influences DTS through two ways mostly: 1) Dense foliage could break down the large eddy from above mean flow into small eddies, thus reducing the time scales; 2) Coupling and decoupling of flows above and within canopy. Flows above and within canopy during growth-stopped period were coupling, while decoupling during growth period. From Fig 2 and Fig 3, we can see that similar patterns occurred at all heights above and within canopy under the coupling condition (during growth stopped seasons), while inversed patterns occurred during decoupling periods (growth season).

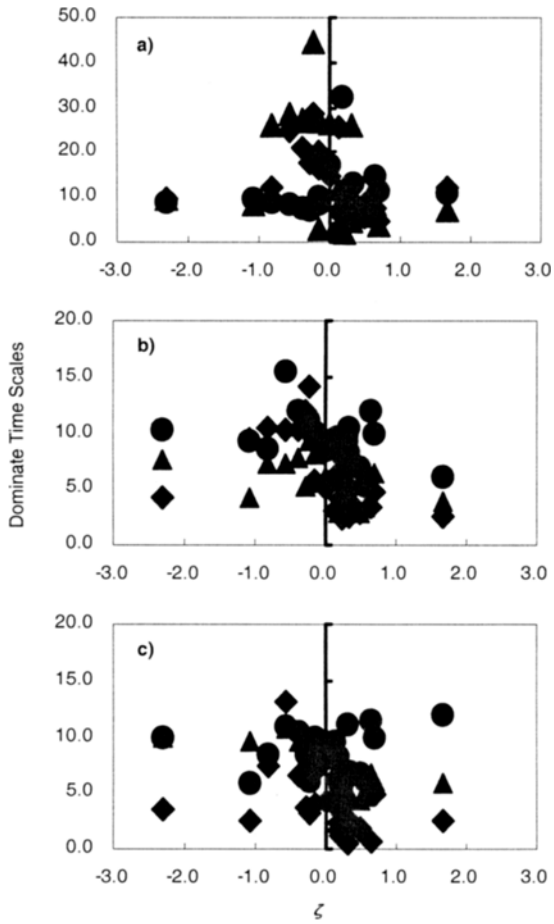

Fig. 2 Effect of atmospheric stability on time scales across canopy-atmosphere interface during growth period
a)— *u* component, b)—*v* component, c)—w component
◆ 32m, ▲ 22m ,● 16m

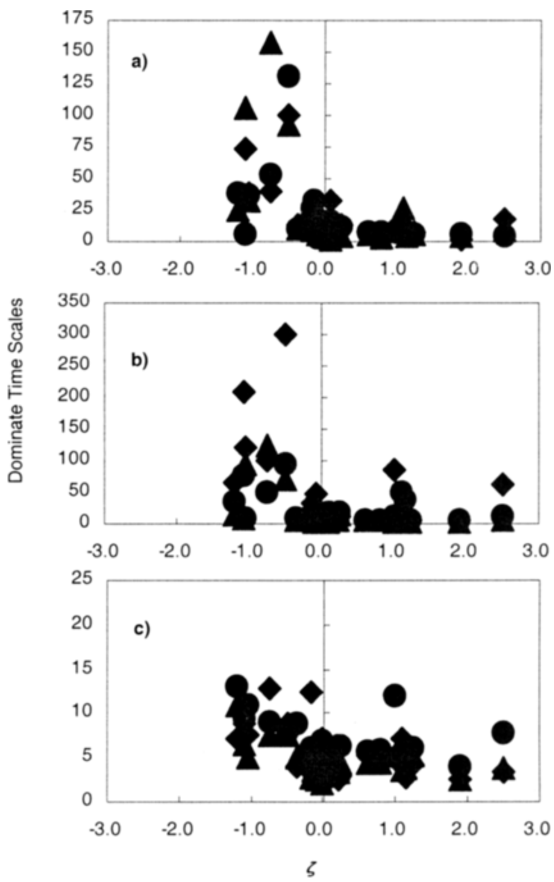

Fig. 3 Effect of atmospheric stability on time scales across canopy-atmosphere interface during growth-stopped period
a)— *u* component, b)—*v* component, c)—w component;
◆ 32m, ▲ 22m ,● 16m

Average characteristics of DTS and DCR

DCR and ζ were poorly correlated. We calculated the average values of DCRs and DTSes (Table 1). The average DTSes of Stream-wise and lateral velocity components were larger than that of vertical components, while the average DCR of vertical component was larger than that of Stream wise and lateral velocity components. DTSes and DCRs under unstable condition were larger than that under stable condition, implying the dominant Large-scale eddies under unstable condition and Small-scale eddies under stable condition.

Conclusions

Timescale is one of the most important scales figuring turbulence. Traditional integral timescale is the indicator for average life of turbulence eddies. Eddies of different scales and their influence could be parted with MSM.

Dominant process for matter and energy exchange across canopy-atmosphere interface was the coherent structure, and its contributions to heat and moment fluxes were larger than 70% (Zhang 2002). Coherent structure was controlled by canopy bulk wind shear (Raupach *et al.*

1996; Brunet and Irvine 2000) and buoyancy (Gao *et al.* 1989; Shi and Shu 1997). DTSes and DCRs here may be the timescale and contribution ratios of coherent structure. DTSes of stream wise and lateral velocity components were larger than that of vertical velocity component, while DCRes of vertical velocity component were larger than that of the stream wise and lateral velocity components. Influence of atmospheric stability on DCR and DTS was nonlinear. DTSes under unstable conditions were larger than that of DTSes under stable conditions; DTSes and DCRs were determined upon the original characteristics of upwind flow under strong stability. Canopy structure would influence DTSes and DCRs across canopy-atmosphere interface remarkably.

Table 1. Average characteristics of DTSes and DCRs

Height(m)	Items	Growth-Period				Growth-stopped period			
		Stable		Unstable		Stable		Unstable	
		DTS	DCR	DTS	DCR	DTS	DCR	DTS	DCR
	u	8.69	0.84	17.7	0.88	10.9	0.73	27.7	0.89
32	v	4.1	0.79	9.64	0.77	18	0.76	64	0.78
	w	2.22	0.89	5.32	0.99	3.79	0.96	6.22	0.83
	u	8.8	0.79	22.4	0.8	8.06	0.79	35.9	0.79
22	v	5.11	0.86	6.89	0.89	6.01	0.73	28.2	0.75
	w	5.73	0.98	8.96	0.99	3.9	0.92	4.87	0.89
	u	11.1	0.84	8.57	0.96	8.07	0.73	26	0.77
16	v	8.71	0.82	10.8	0.92	14.7	0.8	23.3	0.77
	w	8.02	1	8.82	1	6.25	1	6.83	0.97

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